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NUCLEAR RADIATION DOSE COMPARISONS OF SMAUG TO AIR TRANSPORT RE--ETC(U)
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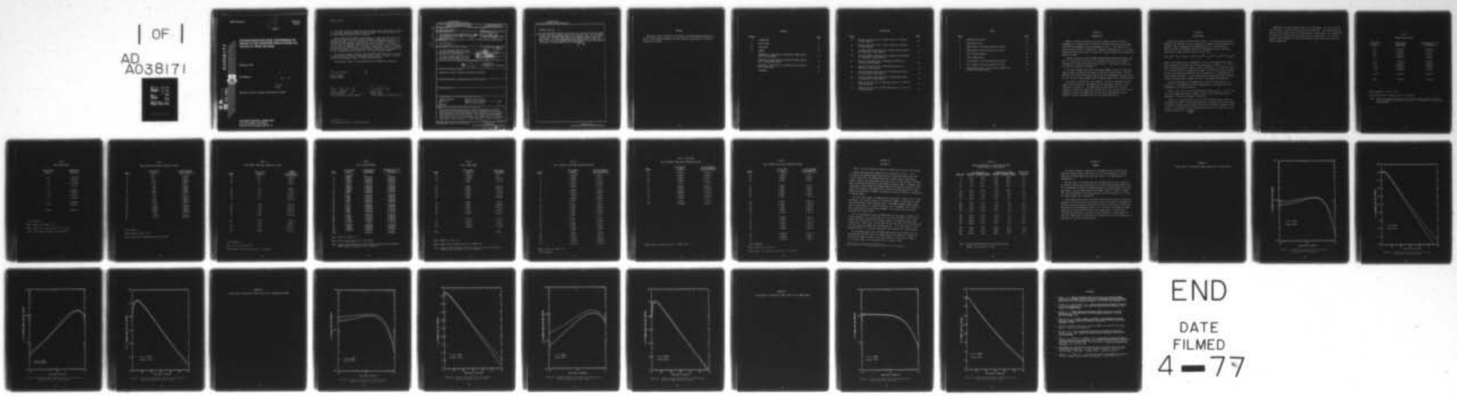

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NUCLEAR RADIATION DOSE COMPARISONS OF SMAUG TO AIR TRANSPORT RESULTS BASED ON THE DLC-31 CROSS SECTIONS

ADA038171

February 1977

Final Report

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AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117

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This report presents comparisons of results obtained from the SMAUG computer code to recently published infinite homogeneous air transport data generated by the ANISN one-dimensional discrete-ordinates computer code, using the DLC-31 cross sections. The comparisons are for $4\pi R^2$ tissue dose from a fission and thermonuclear neutron source and a prompt gamma source over the range of 1 to 600 grams/cm^2. From 10 to 300

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ABSTRACT (cont'd)

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grams/cm^2 the SMAUG neutron tissue dose from a fission source was higher and the resulting secondary gamma tissue dose was lower. For the thermonuclear source both the SMAUG neutron and secondary gamma tissue doses were higher. For the prompt gamma source SMAUG results are lower for ranges less than 100 grams/cm^2, about equal between 100 and 150 grams/cm^2, and higher for ranges greater than 150 grams/cm^2.

sq. cm.

PREFACE

The author wishes to thank Mr. Harry Murphy and Captain Raymond Shulstad of the Air Force Weapons Laboratory for their technical assistance in writing and reviewing this report.

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SECTION I

INTRODUCTION

SMAUG is a computer code which uses mass integral scaling of infinite homogeneous air transport data to calculate the prompt neutron and gamma doses resulting from atmospheric nuclear detonations (ref. 1). This code, which is largely based on Straker's 1969 results reported in ORNL-4464 (ref. 2), has been extensively used over the past five years for systems survivability/vulnerability analysis at AFWL.

Recently, the author used the ANISN one-dimensional discrete ordinates code (ref. 4) to calculate a new set of air transport data based on the recently released DLC-31 cross section data (refs. 5 and 6). The results of these calculations are reported in reference 3.

This report compares the results obtained by SMAUG, based on the ORNL-4464 data, with the new calculations, based on the DLC-31 cross sections. The comparisons are for $4\pi R^2$ tissue dose from fission and thermonuclear sources as well as from a fission-product gamma source for depths ranging from 1 to 600 grams/cm^2.

This report is divided into four sections. Section II describes the data used in the calculations. The comparisons are discussed in section III and summarized in section IV. The comparisons are made graphically in three appendixes: Appendix A contains the comparisons for the neutron fission source; appendix B contains the comparisons for the neutron thermonuclear source; appendix C contains the comparisons for the prompt gamma source.

SECTION II

CALCULATIONS

Reference 3 contains two sets of DLC-31 data: (1) Fluences due to uniform weighted cross sections; and (2) Fluences due to weapons-fission weighted cross sections. Only the weapons-fission weighted data set is considered here. Murphy, of AFWL, has performed a series of least-squares fits to the DLC-31 calculations, using an empiric function of the form:

$$\ell n(T_{i\rightarrow j}(X)) = A_{i\rightarrow j} + B_{i\rightarrow j}X + C_{i\rightarrow j}X^2 + D_{i\rightarrow j}X^{3/2} + E_{i\rightarrow j}X^{1/2} + F_{i\rightarrow j}X^{1/3} + G_{i\rightarrow j}\ell n(X)$$

where X is the depth in air in grams/cm^2; $T_{i\rightarrow j}(X)$ is the number of particles/source particle in receiver group j from source group i; and A, B, C ... G are empiric constants which are functions only of the source, i, and receiver group, j. This function allows one to express the number of particles per source particle for any source/receiver combination over the range of 0.1 to 1000 grams/cm^2 in terms of seven constants. The fits agree with the actual DLC-31 data to within 5 percent and were used to compute the DLC-31 environments presented here.

Since the comparisons are presented as a function of areal density (i.e., grams/cm^2) in one-dimensional infinite homogeneous air, the comparisons are independent of altitude and density.

Table 1 lists the fission and thermonuclear neutron sources. Table 2 lists the fission gamma source used in SMAUG. Tables 3 and 4 contain the tissue responses for neutrons and gammas, respectively.

Tables 5 to 8 present similar data in the DLC-31 energy group structure. The neutron and gamma tissue response reported in references 7 and 8 are banded in the DLC-31 energy group structure using log-log four-point Lagrangian interpolation. The response is then integrated over each DLC-31 energy band, using uniform weighting (i.e., $\frac{\int F(E)dE}{\int dE}$).

Appendixes A, B, and C contain plots of the comparisons. The plots are $4\pi R^2$ rads (tissue) as a function of areal density in grams/cm^2. Each source comparison consists of two graphs; one with the areal density ranging from 1 to 100 grams/cm^2, the other with the areal density ranging from 1 to 600 grams/cm^2. For the two neutron sources (appendixes A and B) the secondary gamma comparison follows the neutron comparison.

Table 1

SMAUG NEUTRON SOURCES

UPPER ENERGY (MeV)	FISSION SOURCE (NEUTRONS)	THERMONUCLEAR SOURCE (NEUTRONS)
15.0	3.9200+19[a]	6.0010+22
12.22	2.2330+20	2.1760+22
10.0	8.7000+20	1.1985+22
8.18	3.4800+21	1.2495+22
6.36	1.7410+22	2.9750+22
4.06	5.4852+22	4.2500+22
2.35	8.4600+22	7.6500+22
1.108	8.4650+22	1.5895+23
0.111[b]	3.8750+21	3.1025+23
TOTAL	2.5000+23	8.5000+23

[a] Read 3.9200+19 as 3.9200×10^{19}

[b] Lower energy limit of energy group 9 is 0.00335 Mev

NOTE: Spectra in reference 2 banded into above energy groups and then multiplied by total number of neutrons for each source. Total numbers of neutrons are from reference 1.

Table 2

SMAUG GAMMA SOURCE

UPPER ENERGY (MeV)	GAMMA SOURCE (PHOTONS)
10.0	1.2648+19[a]
7.0	1.0539+20
5.0	9.5111+20
3.0	2.1437+21
2.0	2.3562+21
1.5	4.0838+21
1.0	3.7741+21
0.7	5.2499+21
0.4	4.5962+21
0.2[b]	2.7062+21
TOTAL	2.9000+22

From reference 9.

[a]Read 1.2648+19 as 1.2648×10^{19}

[b]Lower energy limit of energy group 10 is 0.1 MeV

NOTE: Total number of photons from reference 1.

Table 3

SMAUG NEUTRON TISSUE DOSE CONVERSION FACTORS

GROUP	UPPER ENERGY (MeV)	TISSUE RESPONSE (RAD/NEUTRON/CM^2)
1	15.0	6.255-9[a]
2	12.2	5.774-9
3	10.0	5.153-9
4	8.19	4.996-9
5	6.36	4.486-9
6	4.97	4.120-9
7	4.07	4.066-9
8	3.01	3.428-9
9	2.46	3.154-9
10	2.35	3.050-9
11	1.83	2.619-9
12	1.11	2.013-9
13	0.55	1.292-9
14	0.111	4.259-10
15	3.35-3	1.958-11
16	5.83-4	3.659-12
17	1.01-4	1.153-12
18	2.90-5	1.084-12
19	1.07-5	1.546-12
20	3.06-5	2.667-12
21	1.12-6	4.339-12
22	4.14-7[b]	8.259-12

From reference 1.

[a] Read 6.255-9 as 6.255 x 10^{-9}

[b] Lower energy limit of energy group 22 is 0.0 MeV

Table 4

SMAUG GAMMA TISSUE DOSE CONVERSION FACTORS

GROUP	UPPER ENERGY (MeV)	TISSUE RESPONSE $(RAD/GAMMA/CM^2)$
23	10.0	2.258-9[a]
24	8.0	1.937-9
25	6.5	1.644-9
26	5.0	1.390-9
27	4.0	1.181-9
28	3.0	1.010-9
29	2.5	8.838-10
30	2.0	7.673-10
31	1.66	6.647-10
32	1.33	5.512-10
33	1.00	4.462-10
34	0.80	3.571-10
35	0.60	2.601-10
36	0.40	1.792-10
37	0.30	1.226-10
38	0.20	6.256-11
39	0.10	3.203-11
40	0.05[b]	4.721-11

From reference 1.

[a]Read 2.258-9 as 2.258×10^{-9}

[b]Lower energy limit of energy group 40 is 0.02 MeV

Table 5

DLC-31 NEUTRON SOURCES

GROUP	UPPER ENERGY (MeV)	FISSION SOURCE (NEUTRONS)	THERMONUCLEAR SOURCE (NEUTRONS)
1	1.9640+1[a]	0.0	0.0
2	1.6905+1	4.7132+16	1.0526+20
3	1.4918+1	4.2777+18	9.0612+21
4	1.4191+1	4.2654+18	8.4602+21
5	1.3840+1	1.7605+19	2.9247+22
6	1.2840+1	1.2727+19	1.2977+22
7	1.2214+1	8.1996+19	1.2785+22
8	1.1052+1	1.4158+20	9.1348+21
9	1.0000+1	3.3085+20	6.2749+21
10	9.0494	5.4100+20	5.7271+21
11	8.1873	8.1727+20	4.8650+21
12	7.4082	2.5979+21	7.4705+21
13	6.3763	8.7367+21	1.5502+22
14	4.9659	1.9032+21	3.5922+21
15	4.7237	6.8934+21	1.0876+22
16	4.0657	2.6674+22	2.1976+22
17	3.0119	2.6245+22	1.9046+22
18	2.3852	4.1440+21	3.1397+21
19	2.3069	2.8012+22	2.2236+22
20	1.8268	5.4501+22	5.2714+22
21	1.1080	4.9375+22	7.2019+22
22	5.5023-1	3.4973+22	8.3466+22
23	1.1576-1	1.0101+20	2.6256+21
24	1.1109-1	1.1869+21	6.7040+22
25	5.2475-2	1.1135+21	8.7371+22
26	2.4788-2	1.6914+20	1.4917+22
27	2.1875-2	8.5906+20	8.1860+22
28	1.0333-2	5.6327+20	5.9712+22
29	3.3546-3[b]	9.4888+14	1.0798+17
TOTAL		2.5000+23	8.5000E23

[a]Read 1.9640+1 as 1.9460 x 10^1

[b]Lower limit of energy group 29 is 1.2341-3 MeV

NOTE: Spectra from reference 3 and total number of neutrons from reference 1. Energy groups 30 through 37 have 0.0 neutrons.

Table 6

DLC-31 GAMMA SOURCE

GROUP	UPPER ENERGY (MeV)	GAMMA SOURCE (PHOTONS)
38	1.4000+1[a]	0.000
39	1.0000+1	3.887+18
40	8.0000	8.761+18
41	7.0000	2.632+19
42	6.0000	7.907+19
43	5.0000	2.375+20
44	4.0000	7.136+20
45	3.0000	7.843+20
46	2.5000	1.359+21
47	2.0000	2.356+21
48	1.5000	4.084+21
49	1.0000	3.774+21
50	7.0000-1	4.250+21
51	4.5000-1	3.171+21
52	3.0000-1	3.740+21
53	1.5000-1	1.390+21
54	1.0000-1[b]	8.716+20
TOTAL		2.9+22

[a]Read 1.4000+1 as 1.4000×10^1

[b]Lower energy limit of energy group 54 is 7.0000-2 MeV

NOTE: Spectrum from reference 9 and total number of gammas from reference 1. Energy groups 55 through 58 have 0.0 photons.

Table 7

DLC-31 NEUTRON TISSUE DOSE CONVERSION FACTORS

GROUP	UPPER ENERGY (MeV)	TISSUE RESPONSE (RAD /NEUTRON/CM^2)
1	1.9640+1[a]	8.672-9
2	1.6905+1	7.419-9
3	1.4918+1	6.812-9
4	1.4191+1	6.545-9
5	1.3840+1	6.147-9
6	1.2840+1	5.955-9
7	1.2214+1	5.894-9
8	1.1052+1	5.551-9
9	1.0000+1	5.288-9
10	9.0484	5.047-9
11	8.1873	5.005-9
12	7.4082	4.759-9
13	6.3763	4.484-9
14	4.9659	4.253-9
15	4.7237	4.171-9
16	4.0657	3.978-9
17	3.0119	3.391-9
18	2.3852	3.138-9
19	2.3069	3.035-9
20	1.8268	2.640-9
21	1.1080	2.057-9
22	5.5023-1	1.333-9
23	1.5764-1	7.623-10
24	1.1109-1	5.489-10
25	5.2475-2	3.116-10

[a]Read 1.9640+1 as 1.9640 x 10^1

From reference 7

Table 7 (continued)

DLC-31 NEUTRON TISSUE DOSE CONVERSION FACTORS

GROUP	UPPER ENERGY (MeV)	TISSUE RESPONSE ($RAD/NEUTRON/CM^2$)
26	2.4788-2	2.074-10
27	2.1875-1	1.466-10
28	1.0333-2	6.614-11
29	3.3546-3	2.276-11
30	1.2341-3	9.132-12
31	5.8295-4	3.663-12
32	1.0130-4	1.176-12
33	2.9023-5	1.110-12
34	1.0677-5	1.612-12
35	3.0590-6	2.742-12
36	1.1254-6	4.457-12
37	4.1400-7[b]	1.135-11

[b]Lower energy of energy group 37 is 1.0000-11 MeV

Table 8

DLC-31 GAMMA TISSUE DOSE CONVERSION FACTORS

GROUP	UPPER ENERGY (MeV)	TISSUE RESPONSE ($RAD/GAMMA/CM^2$)
38	1.4000+1[a]	2.743-9
39	1.0000+1	2.256-9
40	8.0000	1.984-9
41	7.0000	1.792-9
42	6.0000	1.593-9
43	5.0000	1.390-9
44	4.0000	1.180-9
45	3.0000	1.010-9
46	2.5000	8.832-10
47	2.0000	7.428-10
48	1.5000	5.803-10
49	1.0000	4.239-10
50	7.0000-1	2.970-10
51	4.5000-1	1.928-10
52	3.0000-1	1.077-10
53	1.5000-1	4.938-11
54	1.0000-1	3.431-11
55	7.0000-2	2.948-11
56	4.5000-2	4.375-11
57	3.0000-2	9.665-11
58	2.0000-2[b]	3.250-10

From reference 8

[a]Read 1.4000+1 as 1.4000×10^1

[b]Lower energy limit of energy group 58 is 1.0000-2 MeV

SECTION III

DISCUSSION

Table 9 lists the percent differences of SMAUG from the DLC-31 calculations.

Before evaluating these comparisons two caveats are in order. First, the neutron and secondary gamma data reported in ORNL-4464 ranges from 8.325 to 199.8 grams/cm^2*, and SMAUG extrapolates to obtain answers beyond these ranges. Second, the prompt gamma data ranges from 1 to 300 grams/cm^2, and SMAUG again extrapolates these data to get answers at greater depths. Therefore, the comparisons reflect differences between SMAUG's data base and the DLC-31 calculations out to ranges of 200 grams/cm^2 for neutrons and 300 grams/cm^2 for prompt gammas and differences in SMAUG's extrapolation scheme and the DLC-31 calculations at greater depths.

For the fission source the SMAUG neutron tissue dose is higher for all ranges considered. At an areal density of 300 grams/cm^2 SMAUG is 143.6 percent higher and at 600 grams/cm^2 1005.5 percent higher. The SMAUG secondary gamma tissue dose is lower except at 1 gram/cm^2, the cross over is between 1 and 5 grams/cm^2. At an areal density of 300 grams/cm^2 SMAUG is 12.7 percent lower and at 600 grams/cm^2 40.2 percent lower.

For the thermonuclear source the SMAUG neutron tissue dose is higher for all ranges considered. At an areal density of 300 grams/cm^2 SMAUG is 49.8 percent higher and at 600 grams/cm^2 569.7 percent higher. The SMAUG secondary gamma tissue dose is higher from 1 to 350 grams/cm^2 and lower from 400 to 600 grams/cm^2, with the cross over between 350 and 400 grams/cm^2. At an areal density of 300 grams/cm^2 SMAUG is 5.5 percent higher and at 600 grams/cm^2 30.1 percent lower.

For the prompt gamma source the SMAUG gamma tissue dose is lower from 1 to 100 grams/cm^2, with the cross over between 100 and 150 grams/cm^2. From 150 to 600 grams/cm^2 SMAUG is higher. At an areal density of 300 grams/cm^2 SMAUG is 12.7 percent higher and at 600 grams/cm^2 53.7 percent higher.

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*For the 12.2 - 15.0 MeV group data are given to 532.8 grams/cm^2.

Table 9

PERCENT DIFFERENCES IN TISSUE DOSE OF SMAUG
FROM FITTED DLC-31 CALCULATIONS

GRAMS/CM^2	FISSION SOURCE NEUTRONS	FISSION SOURCE SECONDARY GAMMAS	THERMONUCLEAR SOURCE NEUTRONS	THERMONUCLEAR SOURCE SECONDARY GAMMAS	PROMPT GAMMA SOURCE
1	21.8	32.5	31.3	216.8	-4.7
5	10.9	-3.6	22.8	68.1	-3.4
10	5.0	-12.1	18.2	41.8	-3.2
25	4.2	-15.7	15.9	26.7	-2.8
50	13.2	-10.1	16.5	23.0	-2.7
100	31.4	-7.2	17.9	15.2	-0.3
150	48.8	-9.3	19.3	10.2	4.1
175	58.3	-10.5	20.3	9.0	6.3
200	64.2	-11.5	21.7	8.3	8.4
225	81.8	-12.1	24.9	7.8	10.1
250	98.8	-12.3	30.7	7.4	11.3
275	119.5	-12.4	39.0	6.6	12.2
300	143.6	-12.7	49.8	5.5	12.7
350	203.0	-14.4	79.5	2.3	14.7
400	280.4	-17.7	122.3	-2.6	18.7
450	382.8	-22.4	183.1	-8.6	24.5
500	523.0	-28.0	269.2	-15.5	32.0
550	720.5	-34.1	392.2	-22.8	41.6
600	1005.5	-40.2	569.7	-30.1	53.7

NOTE: The percent differences are calculated by using:
$\left((\mathrm{SMAUG} - \mathrm{DLC\text{-}31})/\mathrm{DLC\text{-}31}\right) \times 100.0$

SECTION IV

SUMMARY

This report presents a comparison of the SMAUG and DLC-31 $4\pi R^2$ neutron, gamma and secondary gamma tissue dose for fission and thermonuclear neutron sources and a prompt gamma source over the range of 1 to 600 grams/cm^2 in homogeneous air.

Over the range of the SMAUG data base the SMAUG neutron tissue dose from the neutron fission source was higher and the resulting secondary gammas lower. For the thermonuclear source the SMAUG neutron and secondary gamma tissue doses were higher. For the prompt gamma source SMAUG results are lower for ranges less than 100 grams/cm^2, about equal between 100 and 150 grams/cm^2, and higher for ranges greater than 150 grams/cm^2.

If one assumes that systems survivability/vulnerability analysis requires an accuracy of 25 to 50 percent, then table 9 shows this accuracy is exceeded for neutron tissue doses beyond 150 grams/cm^2 for the fission source and beyond 300 grams/cm^2 for the thermonuclear source. This criterion is exceeded for gamma tissue dose at 600 grams/cm^2 for the prompt gamma source. Since systems survivability/vulnerability analysis is often performed at ranges beyond 150 grams/cm^2, SMAUG should be rewritten to incorporate the infinite homogeneous air data based on the DLC-31 cross sections.

APPENDIX A

TISSUE DOSE AS A FUNCTION OF AREAL DENSITY FOR A FISSION SOURCE

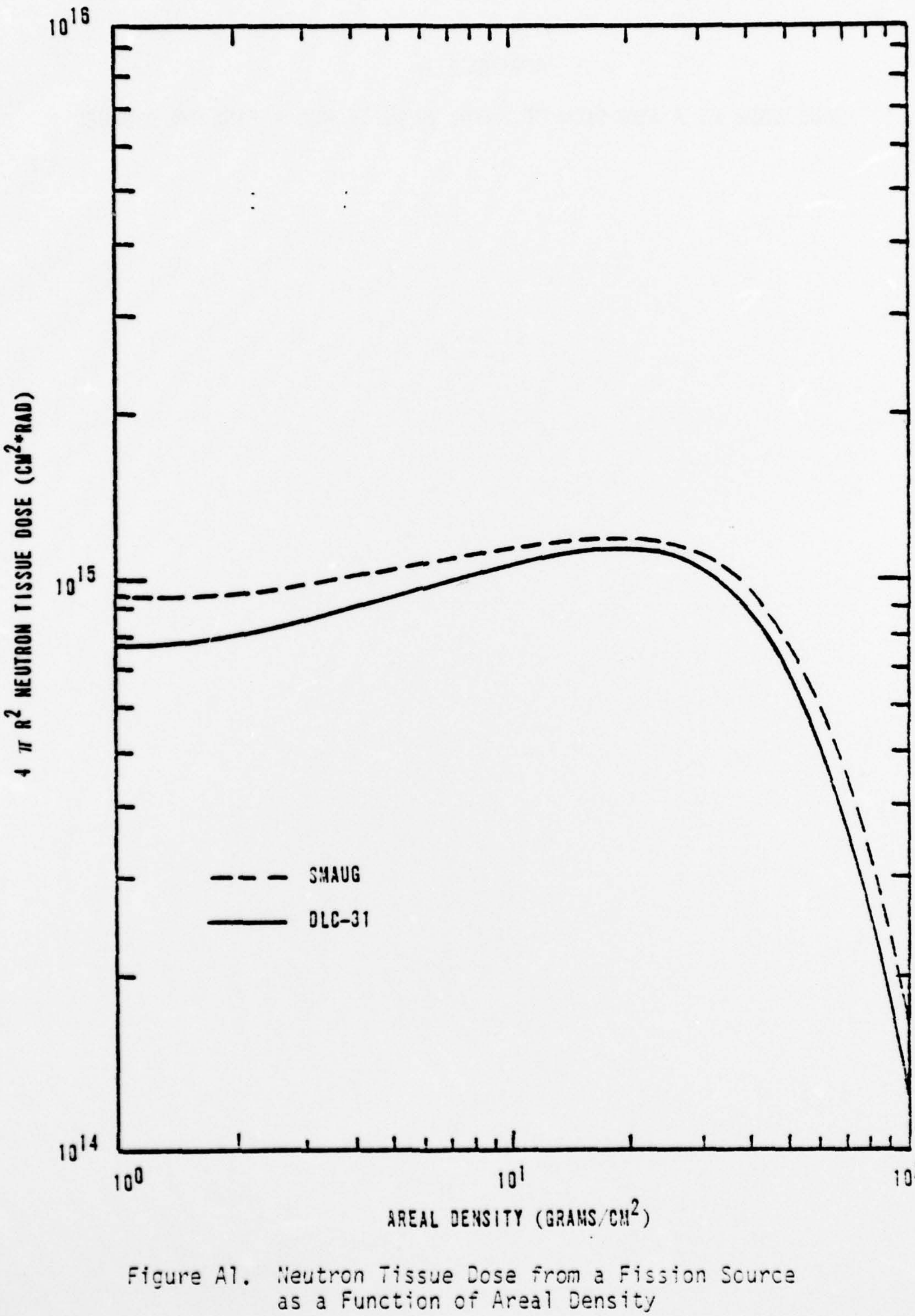

Figure A1. Neutron Tissue Dose from a Fission Source as a Function of Areal Density

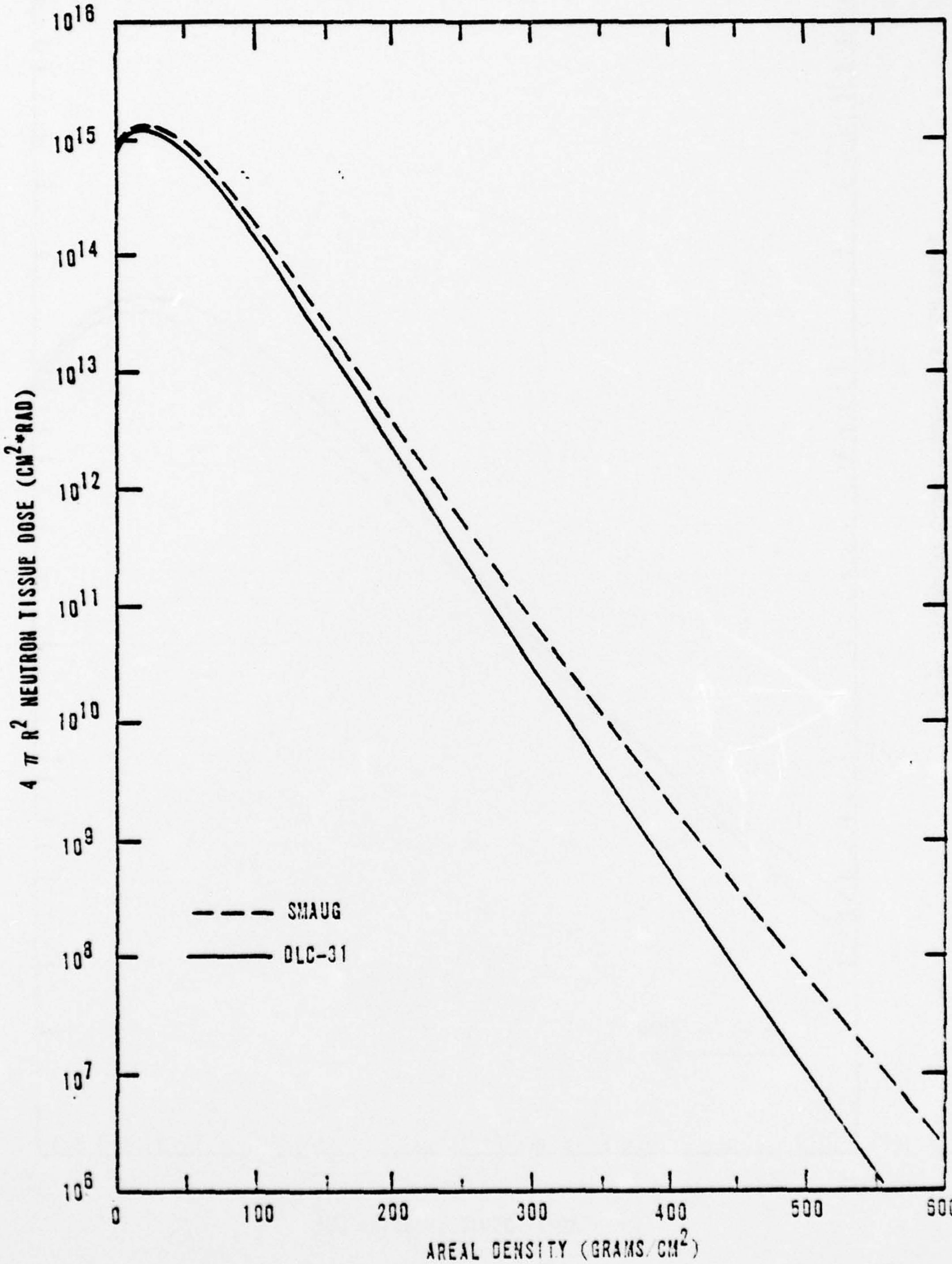

Figure A2. Neutron Tissue Dose from a Fission Source as a Function of Areal Density

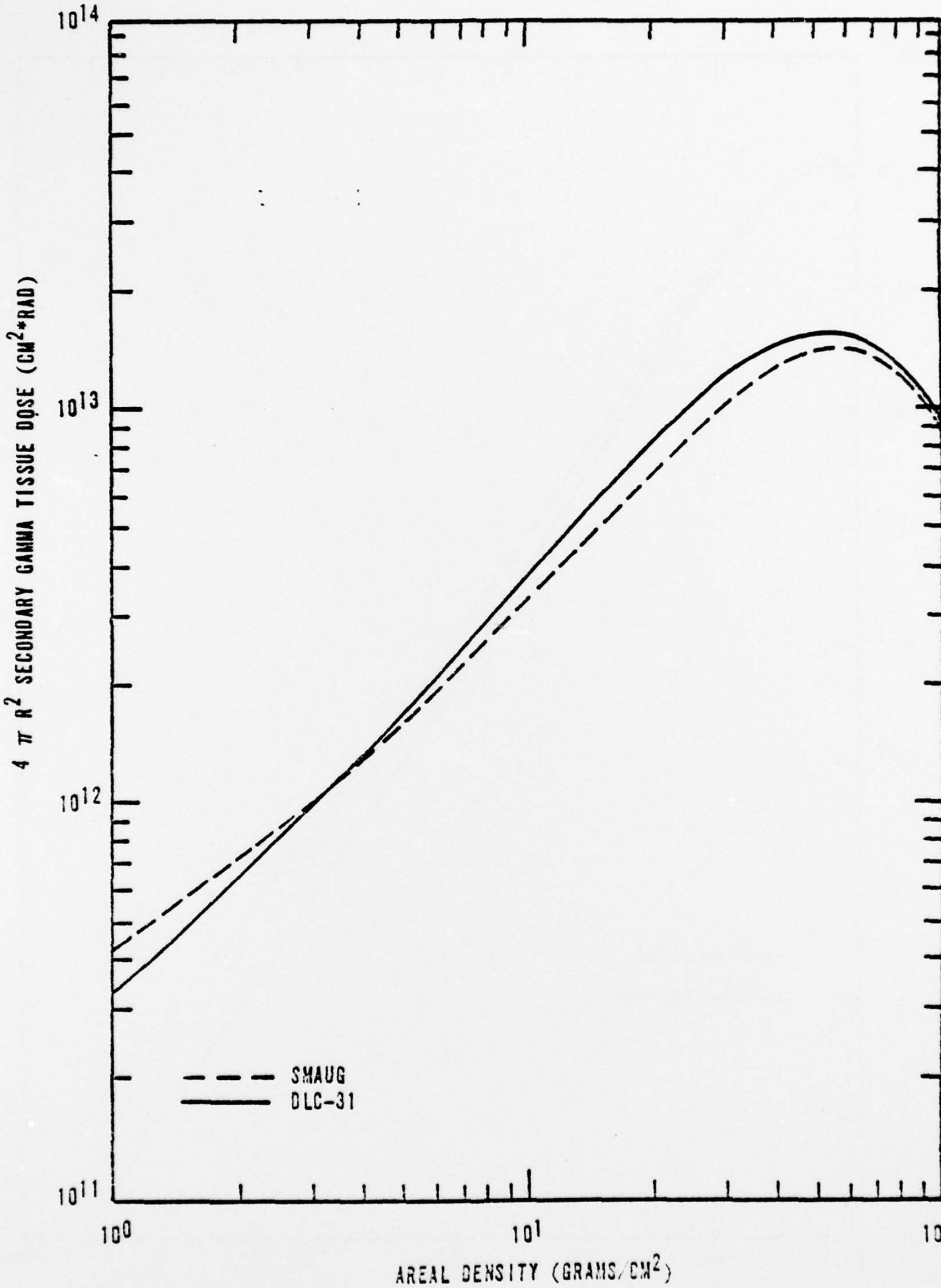

Figure A3. Secondary Gamma Tissue Dose from a Neutron Fission Source as a Function of Areal Density

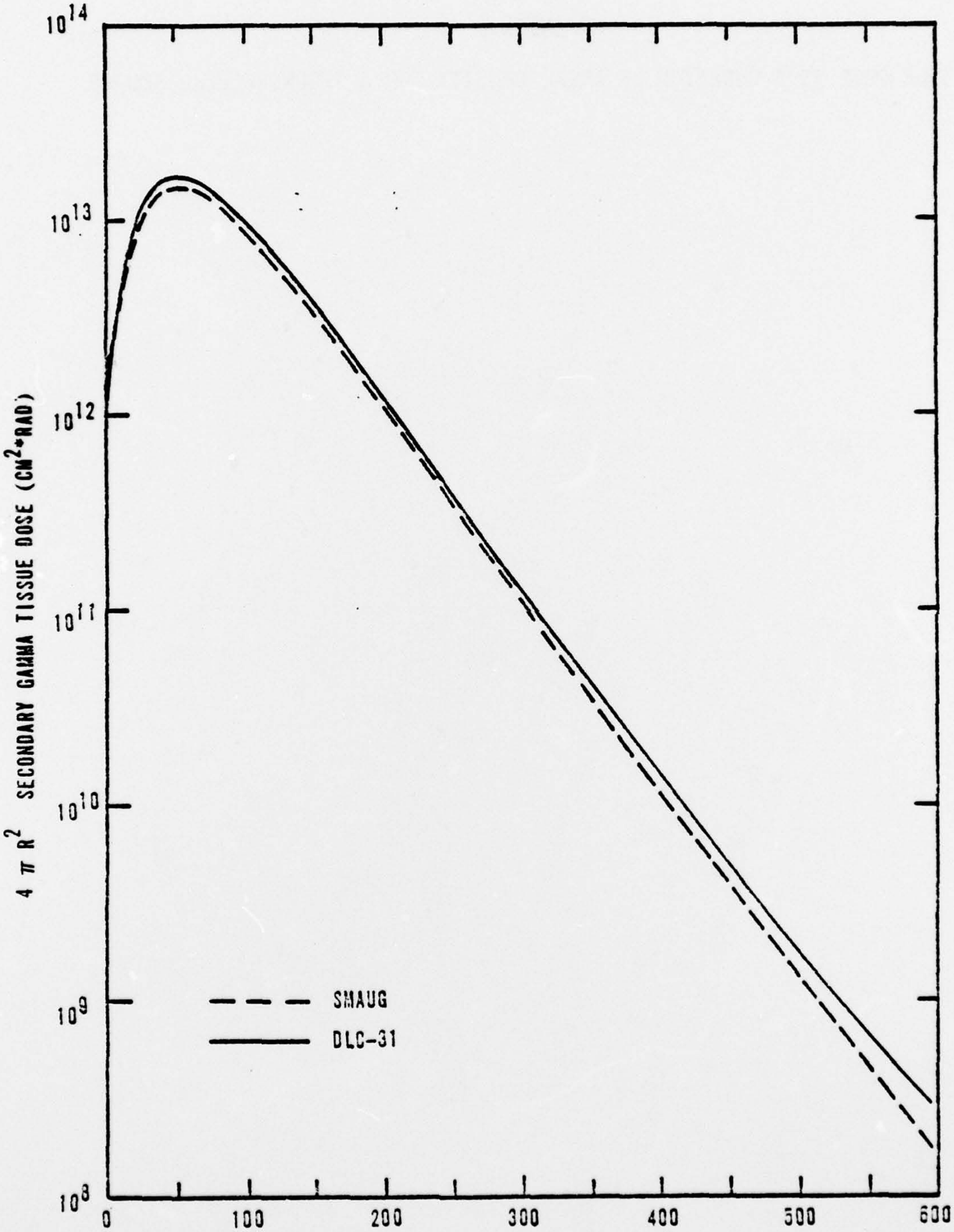

Figure A4. Secondary Gamma Tissue Dose from a Neutron Fission Source as a Function of Areal Density

APPENDIX B

TISSUE DOSE AS A FUNCTION OF AREAL DENSITY FOR A THERMONUCLEAR SOURCE

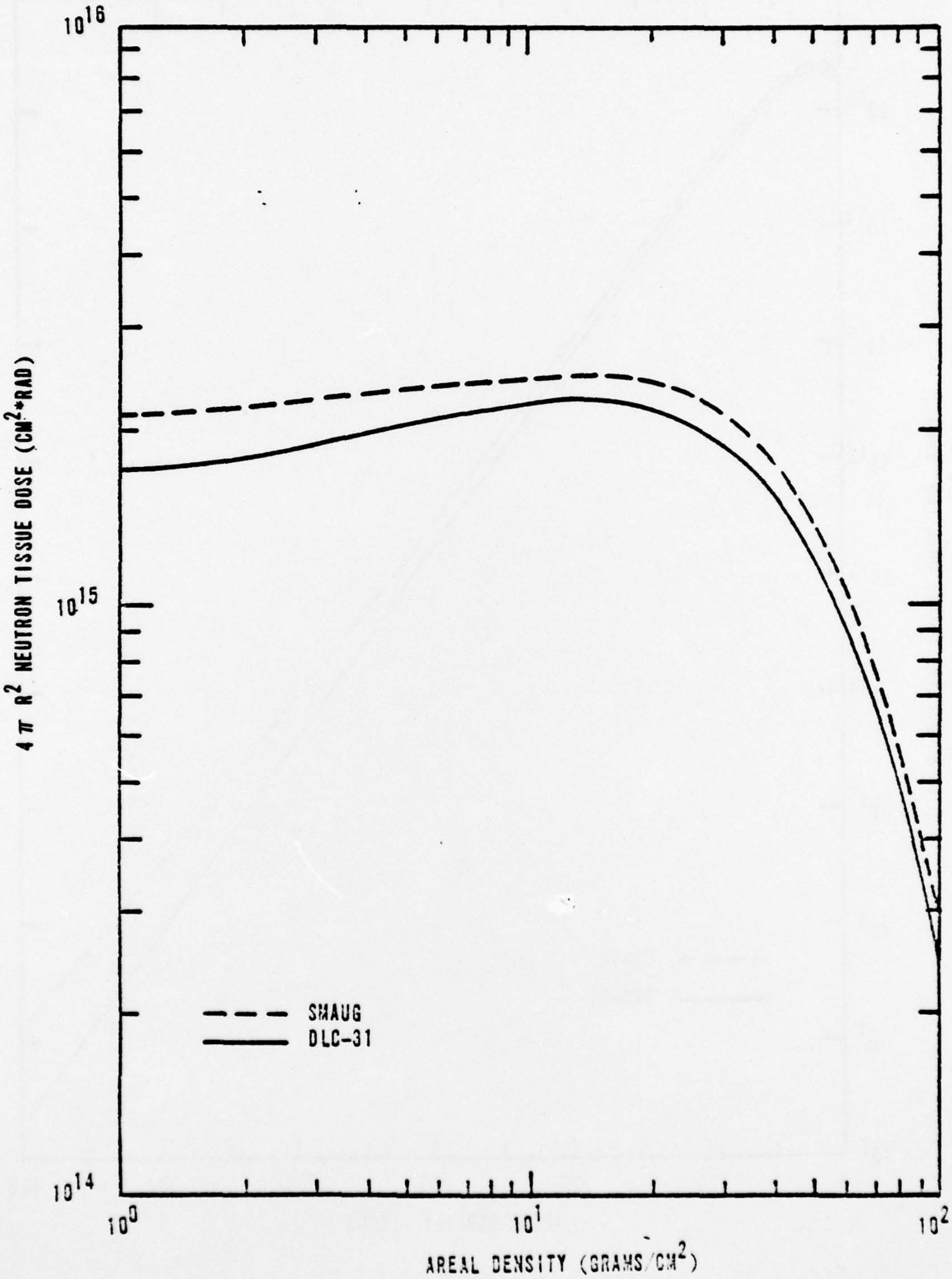

Figure B1. Neutron Tissue Dose from a Thermonuclear Source as a Function of Areal Density

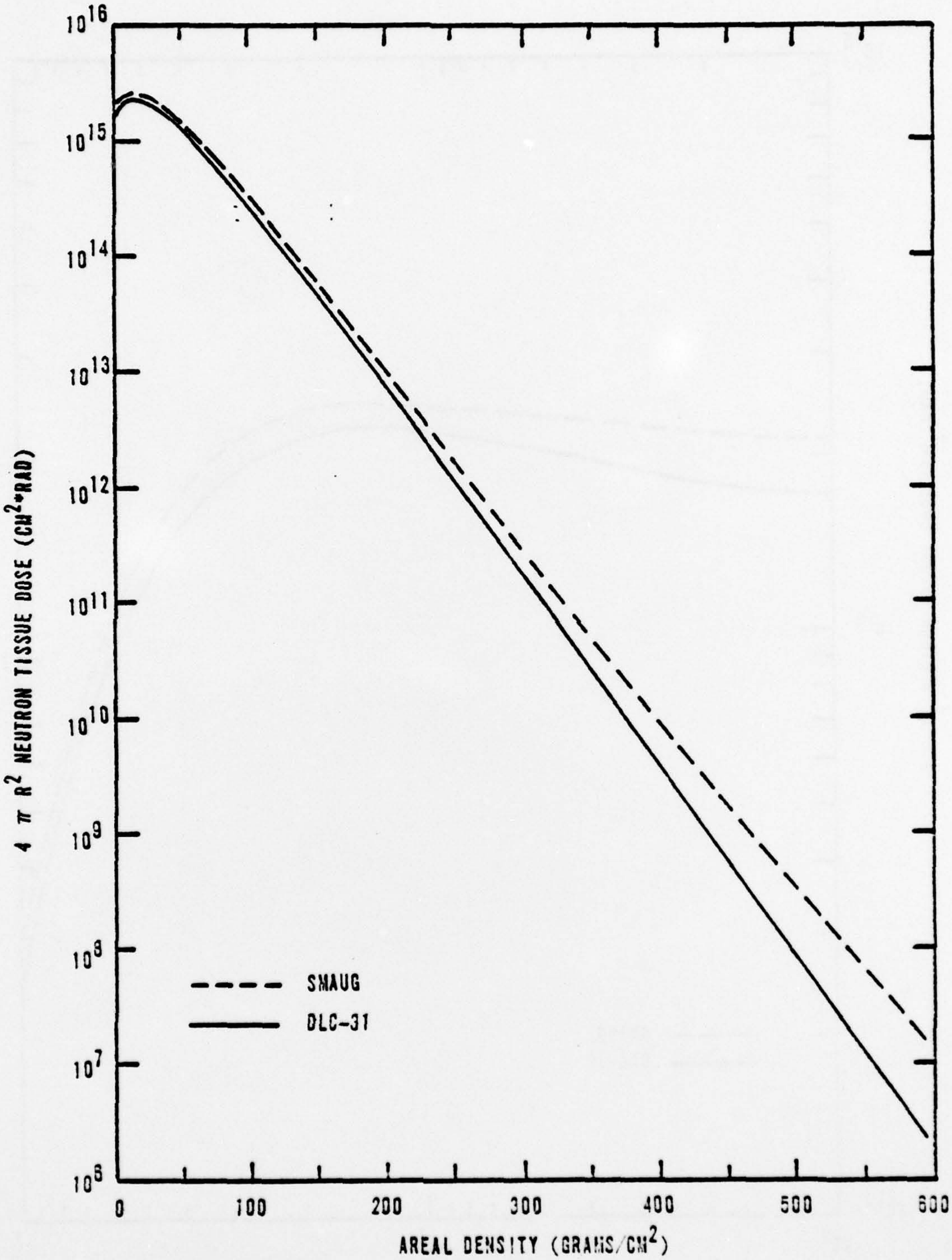

Figure B2. Neutron Tissue Dose from a Thermonuclear Source as a Function of Areal Density

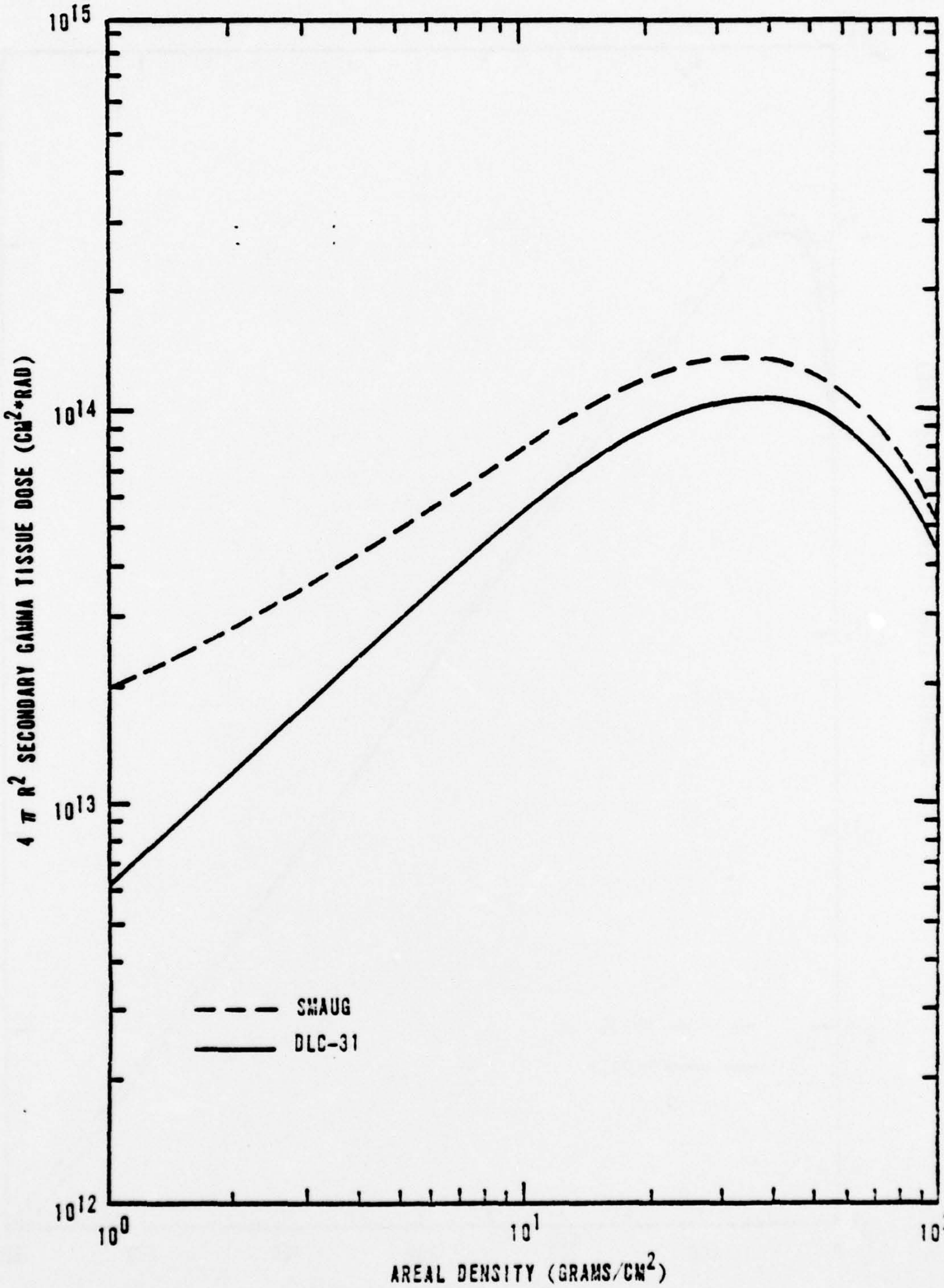

Figure B3. Secondary Gamma Tissue Dose from a Thermonuclear Source as a Function of Areal Density

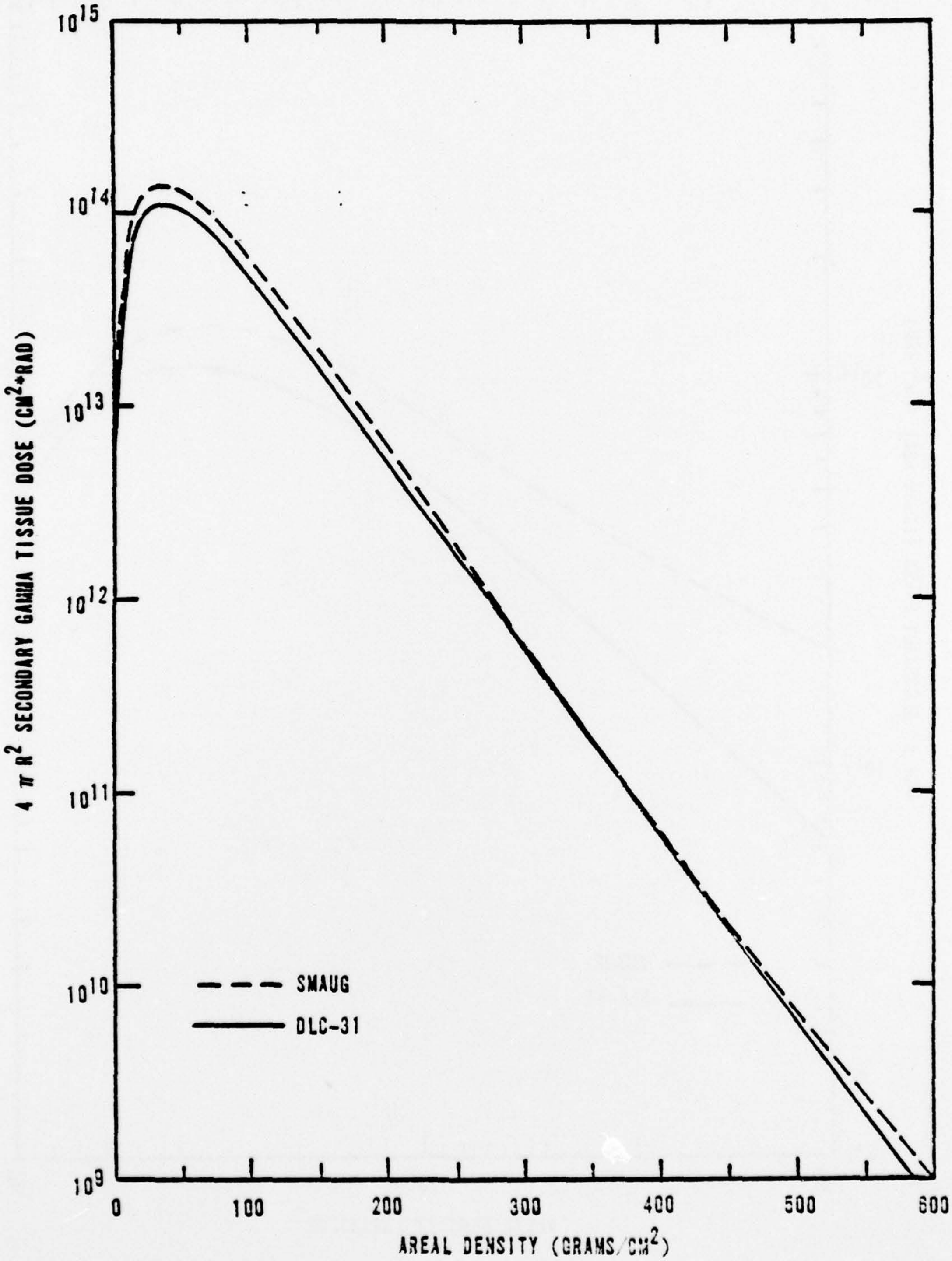

Figure B4. Secondary Gamma Tissue Dose from a Thermonuclear Source as a Function of Areal Density

APPENDIX C

TISSUE DOSE AS A FUNCTION OF AREAL DENSITY FOR A GAMMA SOURCE

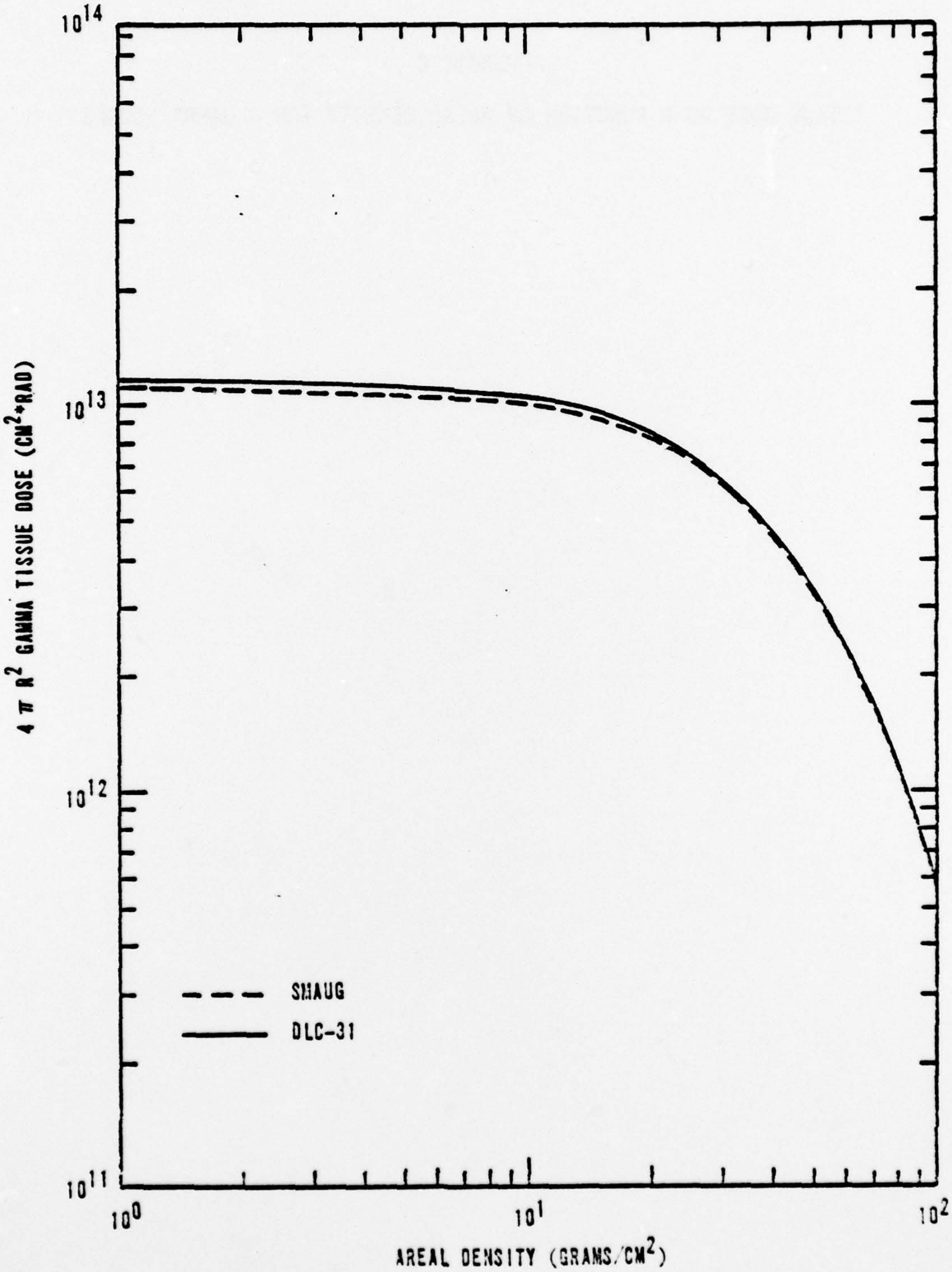

Figure C1. Gamma Tissue Dose from a Prompt Gamma Source as a Function of Areal Density

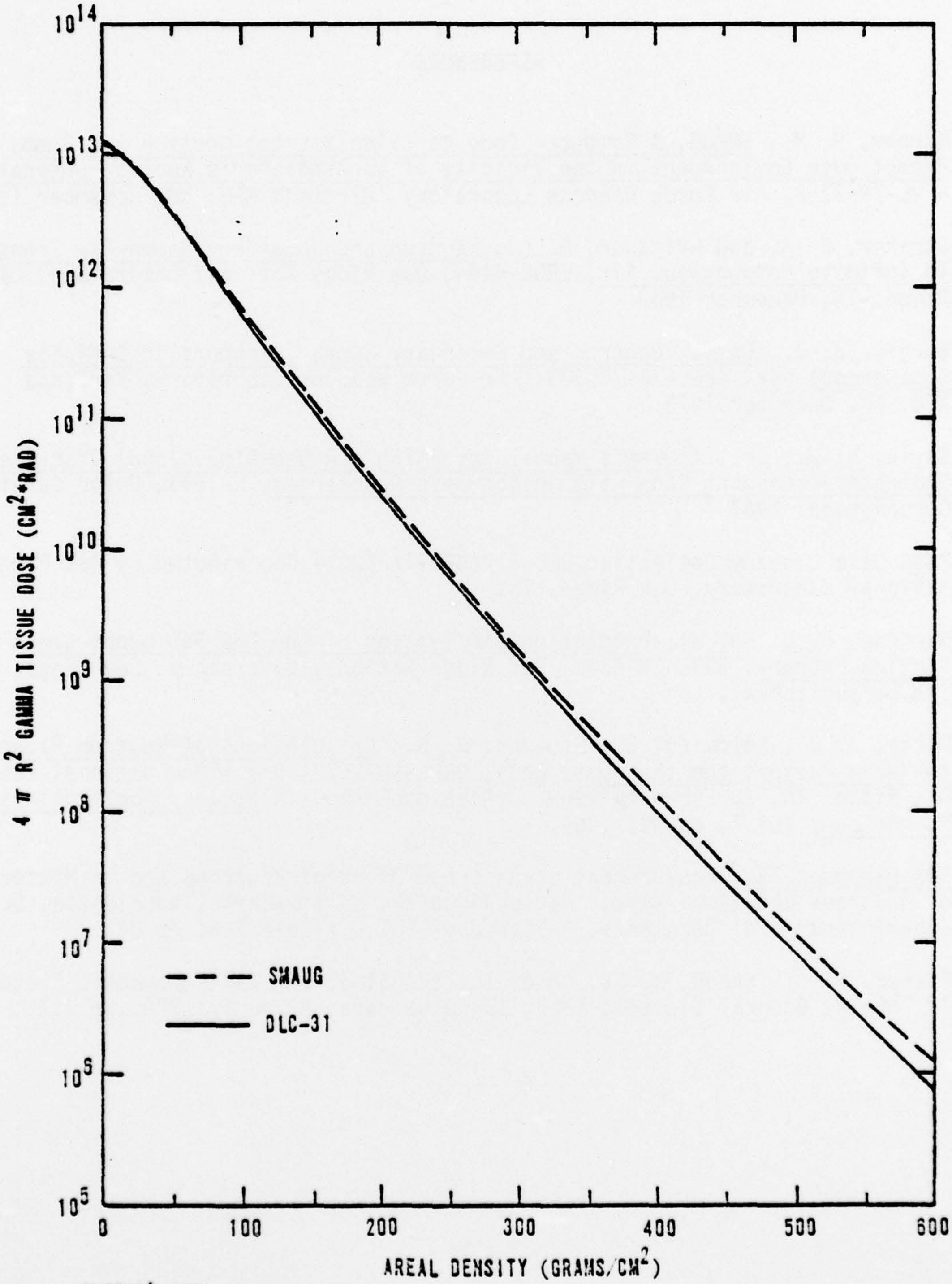

Figure C2. Gamma Tissue Dose from a Prompt Gamma Source as a Function of Areal Density

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